The Cosmic Ray Telescope for the Effects of Radiation Educational Kit

NASA LRO

CRaTER

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Introduction

The Lunar Reconnaissance Orbiter (LRO) is a spacecraft orbiting the moon. Its mission has three main goals: (1) identifying safe landing sites for future human missions to the moon, (2) discovering potential resources on the moon, and (3) characterizing the radiation environment of the moon. This third goal is vital to protecting future astronauts journeying into deep space.

LRO carries onboard seven scientific instruments. The primary one for analyzing the moon's radiation environment is the Cosmic Ray Telescope for the Effects of Radiation (CRaTER). With it scientists study both the radiation itself and how it might affect the human body.

This booklet contains the background information needed to introduce middle school students to the nature of cosmic rays and how they affect humans. It also describes how CRaTER works. Throughout the booklet are various activities that make the esoteric concepts—even to us scientists sometimes!—real to the students.

The core of this educator's guide comprises four lessons that vary in length. Each lesson has five parts. The first is background information for the teacher. The second is a set of questions for the students. The third contains activities related to the lesson. The fourth is a common misconception associated with the content. Finally, an assessment activity helps the students review what they have learned.

Send questions, comments, or suggestions to Dr. Andrew Jordan (A.P.Jordan@unh.edu).

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National Science Education Standards and Where They Are Met

This series of lessons is designed for grades 6-8. The following list describes the National Science Education Standards (1996) that this education kit meets.

Unifying concepts and processes
- Change, constancy, and measurement (Lesson 1)

Science as inquiry
- Abilities necessary to do scientific inquiry (Lessons 1, 3, and 4)
- Understandings about scientific inquiry (Lessons 1 and 2)

Physical science
- Properties and changes of properties in matter (Lessons 1 and 2)
- Motions and forces (Lesson 1)
- Transfer of energy (Lessons 1, 3 and 4)

Life science
- Structure and function in living systems (Lesson 3)

Earth and space science
- Earth in the solar system (Lessons 1 and 2)

Science and technology
- Abilities of technological design (Lessons 2, 3 and 4)
- Understandings about science and technology (Lessons 2, 3, and 4)

Science in personal and social perspectives
- Personal health (Lesson 3)
- Natural hazards (Lesson 3)
- Risks and benefits (Lesson 3)
- Science and technology in society (Lesson 3)

History and nature of science
- Science as a human endeavor (Lesson 1)
- History of science (Lesson 1)

What Your Students Should Already Know

Your students should be acquainted with the following concepts and associated language:
- Scientific notation
- How to calculate speed
- Electric charge
- Structure of atoms, i.e., protons, electrons, atomic nuclei, ionization
- Electromagnetic spectrum
- Radioactivity
- Some astronomy would be helpful but unnecessary
- Cells
- DNA

Motivation for the Students

Imagine that you’re an astronaut on the way to the moon. Earlier today you had a tooth-jarring launch from Earth. You’ve just finished making sure that your spacecraft works correctly (it does, thankfully!). While working, you snuck peeks at the stunning earth—a single glance sweeping across entire continents.

Now it’s the end of a long day; you’re exhausted and ready to sleep. You settle into your sleeping bag, enjoying the strange feeling of weightlessness. The soft whirr of the air supply is a comforting sound. You close your eyes and clear your mind.

A tiny white flash appears. You ignore it. But half a minute later, you see another—then another. A few times each minute another white flash appears. You open your eyes and look around the spacecraft. Everything seems normal. “Boy, I must be stressed,” you think to yourself. When you close your eyes again, the flashes start again.

In the morning, after a long, restless night of trying to ignore the flashes, you mention them to your crewmates. To your surprise, they saw them, too! Then you remember something you learned a long time ago in middle school: the flashes are caused by cosmic rays hitting your eyeballs. In this series of lessons, you will learn what cosmic rays are and how they can affect the human body. You will also learn how scientists detect these strange and fascinating particles.

Lesson 1: The discovery and nature of cosmic rays

Objectives: Students will learn how cosmic rays were discovered and what they are. They will understand how small and fast they are.

1A: Background material for the teacher

We usually think of astronomers studying very big things like stars and galaxies. Astronomers also talk about vast distances like thousands of light years. But did you know that astronomers also study some of the smallest known objects in the universe? An important example of such tiny objects is the cosmic ray. Even though cosmic rays are small, they are still the most energetic particles in the universe.

The discovery of these small but energetic particles began accidentally in the early twentieth century, when scientists found that their electroscopes could not store charge indefinitely. An electroscope is a device that stores electric charge. It contains a neutral gas to insulate the stored charged. That charge could leak from electroscopes surprised scientists; this meant that the gas was not neutral. Somehow the gas inside the electroscopes was becoming slightly ionized, creating a route to short out the charge. No matter the amount of shielding, such as lead, electroscopes' charge still leaked. A very penetrative type of radiation must have been ionizing the gas.

Radiation refers to the emission of energy. There are two types: electromagnetic radiation and particle radiation. Electromagnetic radiation includes radio waves, microwaves, infrared, visible, ultraviolet, X-rays, and gamma rays. Scientists refer to all types of electromagnetic radiation as "light," while most non-scientists use the term "light" to refer only to the visible part of electromagnetic radiation. Energetic particles, which could be protons, ions, or electrons, are types of particle radiation.

[Ask Question 1 and/or Questions 2 and 3 here.]

In 1910, a Roman Catholic priest named Theodor Wulf created an experiment to determine the source of the leakage in electroscopes. He thought that the source might be radioactive rocks in the Earth. He carried an electroscope to the top of the Eiffel Tower to see whether the leakage rate would decrease. It did decrease, which implied that some of the radiation was from radioactive materials in the earth. Thus the farther from Earth Wulf moved his electroscope, the less radiation affected it. The decrease in the leakage, however, was less than expected. Another radiation source must also be at work. His results implied that the source of radiation was outside the atmosphere in outer space.

The next year, an Austrian physicist named Victor Hess began a series of balloon trips—some of them dangerous—with electroscopes to measure the leakage. He discovered that with increasing altitude, the rate at first decreased and then began to increase. At an altitude of about 1.5 km (5000 ft.), the leakage was greater than at sea level. He measured the rates even up to 5 km (higher than the Rockies), where the leakage was several times greater than at sea level. (At that time, airplanes were unable to reach such altitudes, nor could they stay aloft for the amount of time necessary for his experiment.) His work conclusively demonstrated that the radiation had an extraterrestrial source. He received the Nobel Prize for his discovery. Fifteen years later, in 1926, Robert Millikan, better known for his work on the electron's charge, helped coin the term "cosmic ray" to describe this radiation raining down on the earth.

[*Optional Information*: We now know that cosmic rays are charged subatomic particles. This is because charged particles do not travel in straight lines in the presence of a magnetic field. Earth has a large magnetic field; this is why you can use a small magnet called a compass to find magnetic north. The physicist Arthur Compton discovered in 1932 that Earth's magnetic field curved the cosmic rays' paths. That meant that the cosmic rays are charged particles and not electromagnetic radiation.] We now know that cosmic rays are subatomic particles. They are electrically charged particles. Cosmic rays are mostly protons and ions, which have positive charges. A small percentage are electrons, which have negative charges.

[*Optional Information*: About 83% are protons, 13% are helium nuclei (also called alpha particles), 3% are electrons, and the final 1% are atomic nuclei more massive than helium (some examples are carbon, oxygen, and iron nuclei).]

Cosmic rays, even though we call them "rays" (like light rays), are not a form of electromagnetic radiation; they are a type of particle radiation. Scientists used that name before they knew what cosmic rays were; some thought that they were high-energy gamma rays. We now know that cosmic rays are charged subatomic particles traveling almost at the speed of light. Most of them are protons, but the name still sticks.

[Ask Question 4 here. Do Activity 1 here.]

[*Optional Information*: Energy in the form of electromagnetic radiation from the stars continually "rains" down on Earth. Similarly, the energy from cosmic rays (particle radiation) is "raining" down on Earth all the time. [Ask Question 5 here.]]

In addition to being subatomic charged particles, cosmic rays are fast. They are so fast that they travel at almost the speed of light, which is 3×10^8 m/s (fast enough to go around the earth seven times in one second). Most cosmic rays travel at one-tenth that speed. But some have been detected traveling at more than 90% of the speed of light. These cosmic rays have the same energy of a fastball thrown by a major league pitcher. Imagine all that energy crammed into a single subatomic particle!

[Ask Question 6 here.]

So cosmic rays are charged subatomic particles traveling almost at the speed of light. What makes them move so fast (i.e., have so much energy)? This question continues to puzzle astronomers. Many, if not most, cosmic rays apparently received their "energy boost" when stars much bigger than our sun explode—an event called a supernova. A supernova is one of the most energetic events in the universe. It releases an enormous amount of energy in a short time (more energy than all the other hundred billion stars in a galaxy!); some of this energy can go into boosting charged particles to high speeds. Scientists continue to search for other sources of cosmic rays.

1B: Questions for the students

Question 1

Can you think of some common examples of particle radiation?

Answer

Older TVs or computer monitors combine both particle and electromagnetic radiation. A small apparatus (electron gun) at the back of the monitor shoots electrons at the screen. These electrons are particle radiation—energy emitted in the form of particles. The screen has a special coating on the inside called phosphor. When electrons hit the screen, they transfer their energy to the phosphor atoms. These atoms reemit the energy in the form of electromagnetic radiation. In other words, the visible light that we see was created by the energy from particle radiation.

Radioactive materials, such as uranium, emit both particle and electromagnetic radiation.

Particle accelerators accelerate particles to high speeds. The biggest example is in Switzerland and operated by CERN (a French acronym for European Organization for Nuclear Research). Some hospitals have much smaller particle accelerators to create energetic protons to treat cancer. So instead of using electromagnetic radiation in the form of X-rays, doctors at such hospitals use particle radiation to kill the cancer cells.

Question 2

Some type of particle or electromagnetic radiation was creating the charge leakage in the electroscopes. What are the possible sources of radiation that could account for the leakage?

Answer

Three possible sources are radioactive materials in the Earth, radiation within the atmosphere, or radiation from outer space.

Question 3

What would you do to discover whether one or more of those possible sources are correct?

Answer

There are three possible sources: Earth, the atmosphere, and space. Since we are near Earth but not space, a good idea would be to get as far away from Earth and as close to space as possible. If Earth is the source, the charge leakage would decrease with distance from Earth. If space is the source, then the leakage would increase with distance from Earth. If the atmosphere is the source, then the leakage would reach a maximum somewhere between Earth and space.

Question 4

Can you guess how many protons are in your body?

Answer

Over ten octillion (10^{28})! Write this number out: 10,000,000,000,000,000,000,000,000,000. That is one hundred thousand times the number of stars in the known universe! It's a good thing you don't have to keep track of all of them.

Question 5

Is the energy from cosmic rays much less than, about equal to, or much more than the energy from starlight?

Answer

The energy from cosmic rays is about the same as the energy from starlight. The reason we notice starlight more is because our eyes can see the electromagnetic radiation (light) from the stars. Our eyes, however, don't detect particle radiation very well. (This question was adapted from *Thinking Physics Is Gedanken Physics*, by Lewis Carroll Epstein, San Francisco: Insight Press, 2005.)

Question 6

How fast does your car go on the highway? How much faster does a cosmic ray go if it travels at one-tenth the speed of light?

Answer

Your car travels at about 130 km/hr (60 mph), or a little over 30 m/s. A "slow" cosmic ray will travel at about one-tenth the speed of light, or 30,000,000 m/s. That means that a cosmic ray is one million times faster than your car. I wonder what the speeding ticket would be?

1C. Activities

Activity 1
Time: 10 minutes

Materials: A copy for each student of the cartoon on the next page

Objective: By discussing these questions, the student should gain a sense of how very small cosmic rays are.

Question

Assume your classroom is 10 m (33 ft) across. Each hair on your head has a diameter (NOT length!) that is much smaller than the width of your classroom. How many hairs would you have to lay side by side to reach across the room?

Answer

Each hair has a diameter of about 100 micrometers. Therefore 100,000 hairs laid side by side would reach across the room. That is about all the hairs you have on your head!

Question

A hair from your head has a diameter of about 100 micrometers. Can you guess how many atoms would fit side by side along your hair's diameter?

Answer

The atom hydrogen is about 10^{-10} m across. That means that one million atoms could fit side by side along the diameter of a single hair!

Question

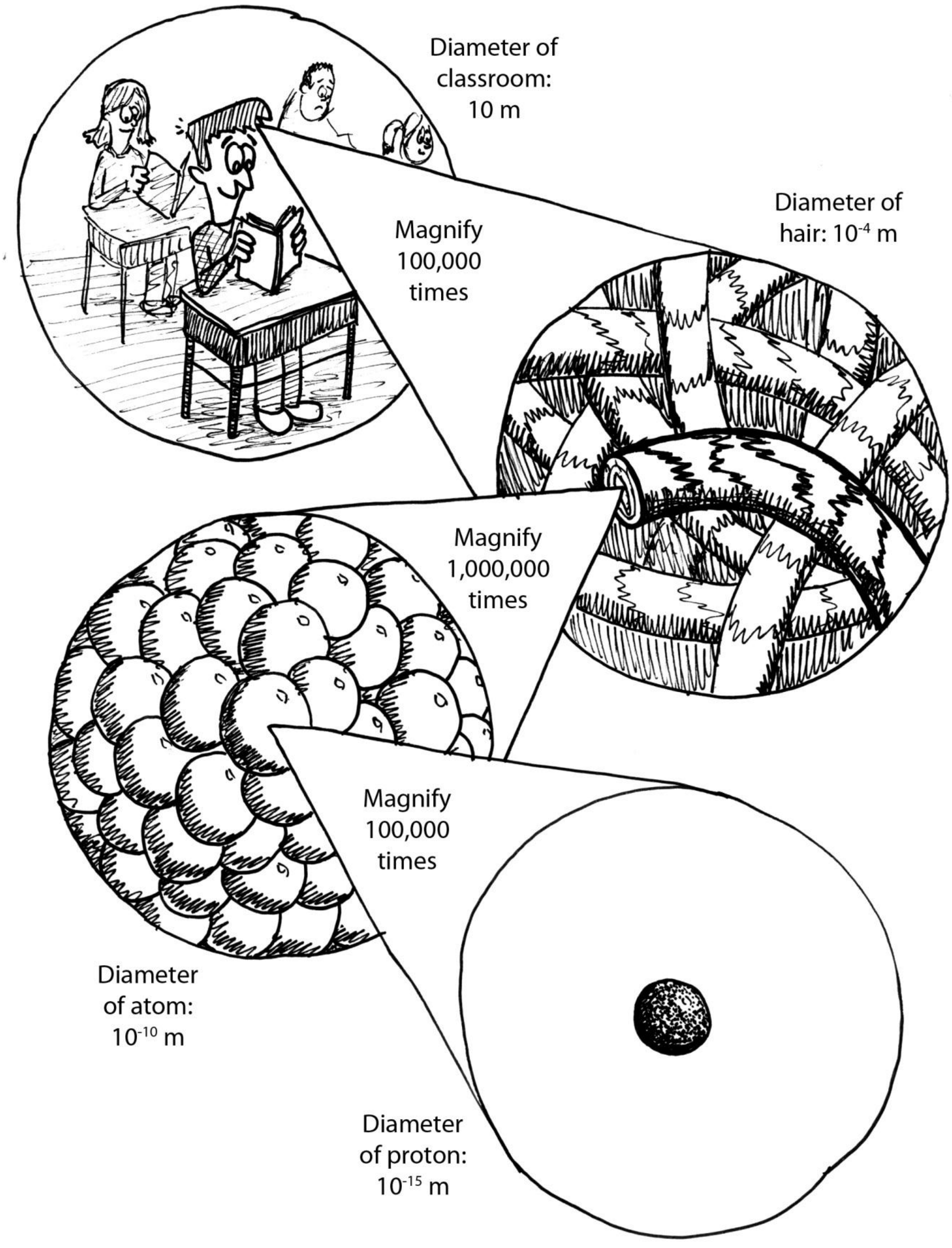
A typical atom is about 10^{-10} m across. Can you guess how many protons would fit side by side along the atom's diameter?

Answer

A proton has a diameter of about 10^{-15} m (that is one femtometer). That means that one hundred thousand protons would fit along the atom's diameter. To give you an idea of what this means, imagine increasing an atom to be the size of your classroom. The diameter of the increased proton at the center of the atom would be the same as the diameter of your hair. A classroom is 100,000 hairs across, and an atom is 100,000 protons across.

This means that atoms are mostly space! In this analogy, the simplest atom, hydrogen, would have a hair-sized proton at the center with an even tinier electron zipping along the walls of the classroom.

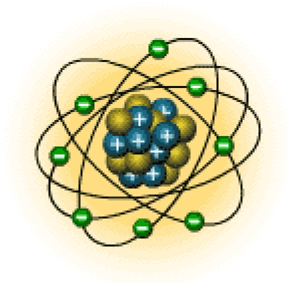
Atoms are very small objects, but subatomic particles, like protons, are much, much smaller. This exercise shows why cosmic rays can travel through your body without hitting anything: you are mostly empty space! The exercise also emphasizes the minuteness of cosmic rays.



Diameter of classroom: 10 m
Magnify 100,000 times
Diameter of hair: 10^{-4} m
Magnify 1,000,000 times
Diameter of atom: 10^{-10} m
Magnify 100,000 times
Diameter of proton: 10^{-15} m

1D. Misconception

Many textbooks show pictures of atoms that look something like this (from a NASA webpage):



While it's okay to have pictures that are not to scale, they can be misleading because they make the nucleus appear to be almost as big as the atom itself! In reality, the diameter of the nucleus is about 100,000 times smaller than that of the atom. You would be unable to see it in this picture!

1E. Assessment

Time: 10-15 minutes
Materials: Pencil, paper, and brains
Objective: The student will review and help others review what they have learned.

Write down three questions about cosmic rays that you now know the answers to. Trade your questions with a classmate and see if you can answer each other's questions.

Lesson 2: How to detect cosmic rays

Objectives: The student will be able to explain two examples of a cosmic ray detector.

2A. Background material for the teacher

To understand the effects of cosmic rays, we need to be able to detect them. A variety of methods exists. One detector you may have seen and heard, especially in movies, is a Geiger counter (see Figure 2a). This instrument can detect various forms of particle radiation and electromagnetic radiation, as discussed in the previous lesson. The sources of particle radiation can be radioactive materials, like uranium, or cosmic rays. The Geiger counter has a small chamber of inert gas. When a photon or subatomic particle passes through the chamber, it can collide with some of the atoms in the gas, stripping them of their electrons. This creates a small current in the gas like the current in electroscopes. The Geiger counter detects the current. If the counter has a speaker, you will hear clicking sounds when the instrument detects radiation.

The Lunar Reconnaissance Orbiter (LRO) carries a detector called the Cosmic Ray Telescope for the Effects of Radiation (CRaTER). Instead of using gas like the Geiger counter, CRaTER uses a solid to detect cosmic rays. It contains six disks made from silicon; they are called solid-state detectors. Such detectors are much more compact than one that uses a gas. A cosmic ray that passes through the detector will create a small current that CRaTER's computer measures. We will discuss this further in Lesson 4.

[Do Activity 1 as a class demonstration.]

Although the cloud chamber seems like a simple device, it was instrumental in discovering new subatomic particles. When cosmic rays collide with atoms in Earth's atmosphere, they create secondary subatomic particles. In 1932, a physicist named Carl Anderson discovered the positron (an antimatter electron, or "electron" with a positive charge) in his cloud chamber. He received the Nobel Prize for this. Anderson next discovered in 1936 a negatively charged particle called the muon. Both particles were the result of using a cloud chamber.

If you could take your cosmic ray detector into outer space, you would see many, many more cosmic rays than here on the ground. That is because the atmosphere shields us from all cosmic rays except for the most energetic. Thankfully, there aren't enough of these really energetic ones to be dangerous to us. Outside the atmosphere, however, there is no protection against any of these particles. That is the topic of the next lesson.

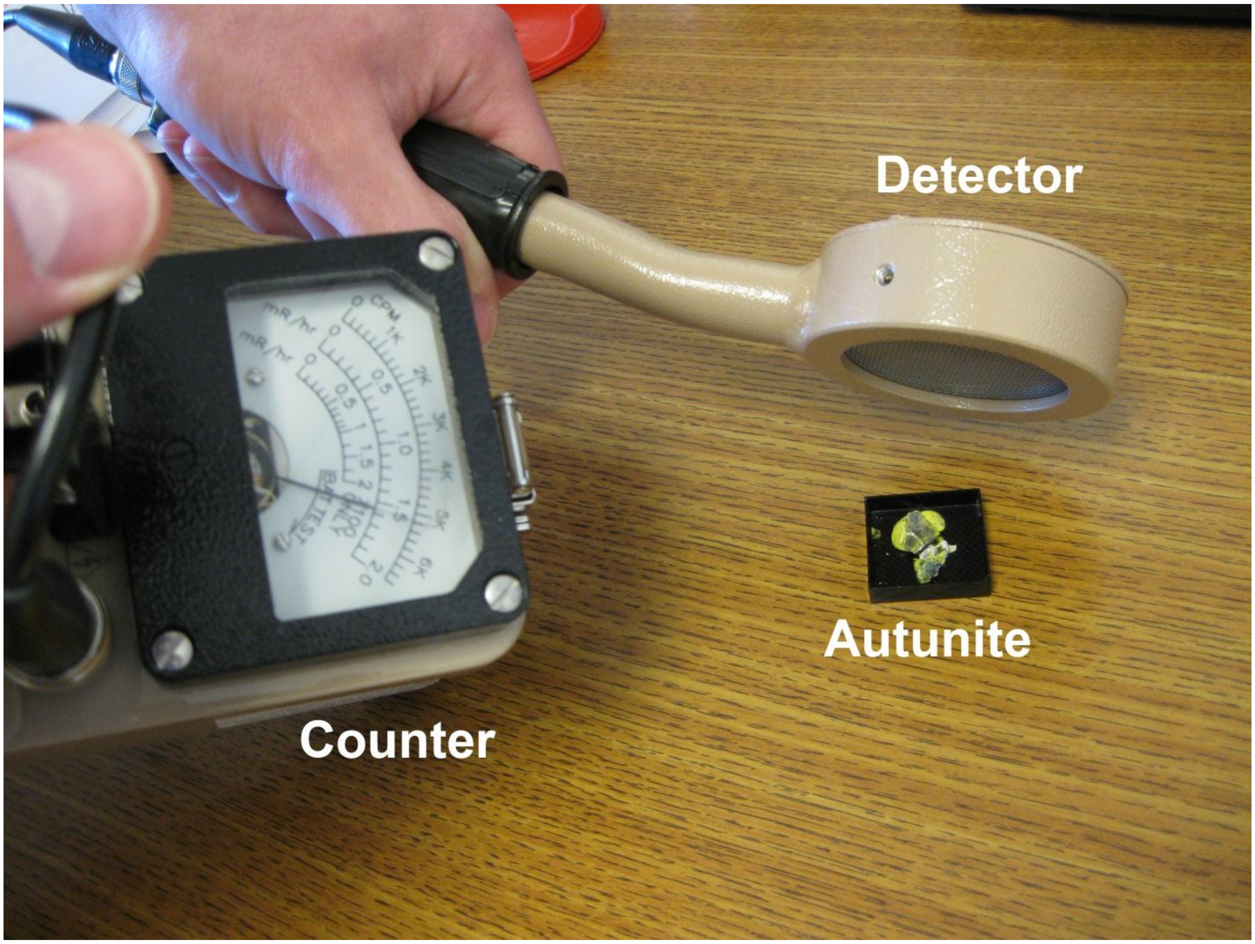


Figure 2a. I am holding a Geiger counter. The detector in my left hand connects by a wire to the counter in my right. The radioactive source in the small black box on the right is the mineral autunite, which contains uranium. If I were to move the detector far away from the autunite, the counter would be very close to zero (but not quite, because of cosmic rays). Don't worry; autunite, although radioactive, is not dangerous!

2C. Activity

Time: 20-30 minutes
Objective: Students will directly see the results of cosmic rays. Students will learn that they can affect us here on Earth.

Pre-activity questions:
Do you think any cosmic rays are going through your classroom right now? How can you tell?

Materials (can be done for about $25)

- Very clear jar with a metal lid (we used a $4 transparent paint can from a craft store: about 6 inches tall and 4 inches in diameter)
- Denatured alcohol (available in the paint section of hardware stores for about $6)
- Black construction paper
- Sponge
- Pen or pencil (for propping the sponge)
- Flashlight (a small one with white LEDs works well)
- Dry ice, which you may be able to find this at an ice cream shop or a grocery store (USE GLOVES, such as oven mitts, when handling dry ice!)
- OPTIONAL: a small radioactive source that emits energetic helium nuclei (alpha particles), e.g. a lead-210 or polonium-210 needle source

Setup

1. Before doing this experiment, you may want to watch a version of this activity done by Jefferson Lab (http://education.jlab.org/frost/cloud_chamber.html). If you don't use a radioactive source, you won't see as many trails. The video will, however, give you an idea of what to look for.
2. Lay the black construction paper on the inside of the lid (there's no need to tape or glue it, although you can see the poster putty I used to keep it in place in Figure 2b).
3. Thoroughly soak the sponge in the alcohol, and squeeze out just a bit of the excess.
4. Use the pen or pencil to jam (no looseness!) the sponge onto the bottom of the jar. This is important because you will be using the jar upside down.
5. Place the lid on. Make sure it seals completely. (If you use a radioactive source, it should sit on the lid.)
6. Turn the jar upside down. Make sure that the pen or pencil is firmly in place; it will keep the sponge from falling. Make sure the construction paper stays on the lid.
7. Let the jar sit for between 5 and 10 minutes. This gives the alcohol vapor enough time to saturate the air inside the jar.
8. Place the jar, still upside down, on top of the dry ice (I had the dry ice in a disposable plastic bowl). See Figure 2b. Wait for no more than five minutes.
9. Darken the room.
10. Shine the flashlight perpendicularly to your eyes and near the jar's lid and watch carefully. You will probably see the fine mist of alcohol rain falling. As the air in the jar cools, the vaporized alcohol condenses and rains to the bottom. The dry ice cools the very lowest part of the jar (closest to the lid) so much that the air becomes supersaturated with alcohol. Supersaturation means that the air contains more alcohol vapor than possible under normal circumstances. With patience and practice, you will see small

contrails form near the lid every few seconds. A contrail looks like a miniature version of a jet contrail in the sky: a long, thin streak of cloud. Most people don't see the contrails until they know what they're looking for. It helps to focus on one spot on the lid. You may have to vary the angle between the light and your eyes to find the best angle.

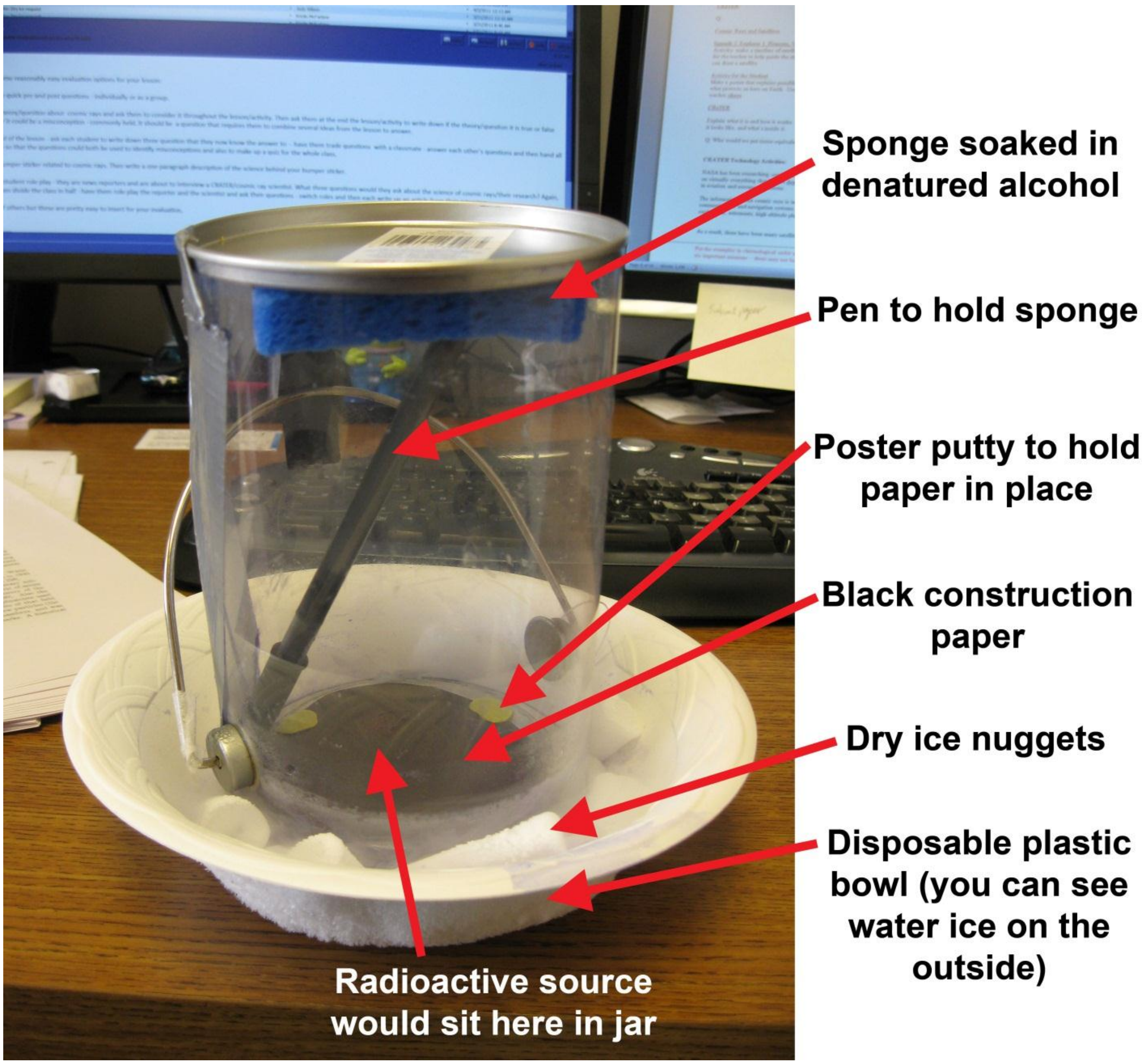


Figure 2b. It's hard to imagine that this simple setup can detect such energetic and minute particles! (I put duct tape along a seam in the jar's side to improve airtightness. This is optional.)

What is happening? Alcohol vapor fills the jar. The lid sits on the dry ice. Therefore the dry ice cools the air near the lid that the air becomes supersaturated with alcohol. The particles created by cosmic rays collide with and ionize the particles in the air. The newly formed ions are the seed particles onto which the alcohol can condense. Although subatomic particles are too small to see, the cloud chamber makes their effects visible.

The original cosmic rays don't cause the contrails you see. The cosmic rays don't make it all the way down to Earth's surface. They collide with molecules in the atmosphere. These collisions create secondary cosmic rays, which are other subatomic particles with less energy. These secondary cosmic rays can collide with other molecules and create more secondaries; this is a cosmic ray air shower. Showers happen all the time, but they are invisible to your eyes. Figure 2c shows a computer simulation of an air shower. You can find air shower movies at: astro.uchicago.edu/cosmus/projects/aires

Think about how far the cosmic rays might have traveled before hitting Earth's atmosphere and creating the tiny contrails you see. Some of them might have come from clear across the Milky Way galaxy! Some of their secondary cosmic rays (a little less than 100 each second) are even getting into your body or passing right through it. Thankfully their effect is minimal.

Optional Activity
If dry ice is unavailable, you can construct an alternative cosmic ray detector using a digital camera able to keep its shutter open more than a minute. Cover the lens so that no light penetrates the camera. Use the highest ISO (International Standards Organization) setting available; this makes the film as sensitive as possible to light. Then set the exposure time for about 5 minutes. You should see small streaks in the resulting image. These are the tracks of secondary cosmic rays. Digital cameras have noise-reducing programming built into their computers, so some cosmic ray tracks may be erased. For further details, see Kendra Sibbernsen's article, "Catching Cosmic Rays with a DSLR," in *Astronomy Education Review*, vol. 9, issue 1, 5 August 2010.

This cosmic ray "noise" is a big problem with highly sensitive digital cameras used for astronomy. Astronomers need to detect faint objects, so they must keep the shutter open for many minutes. The long exposure time, however, means that there will be many cosmic ray tracks in the image. The problem is worse for the Hubble Space Telescope because it is outside the atmosphere where there are more cosmic rays. Astronomers must take multiple images and then carefully subtract the cosmic ray tracks. See blogs.zooniverse.org/galaxyzoo/2010/04/12/how-to-handle-hubble-images for more information and images. (This website is part of Zooniverse, a scientific project in which the public can help classify galaxies.)

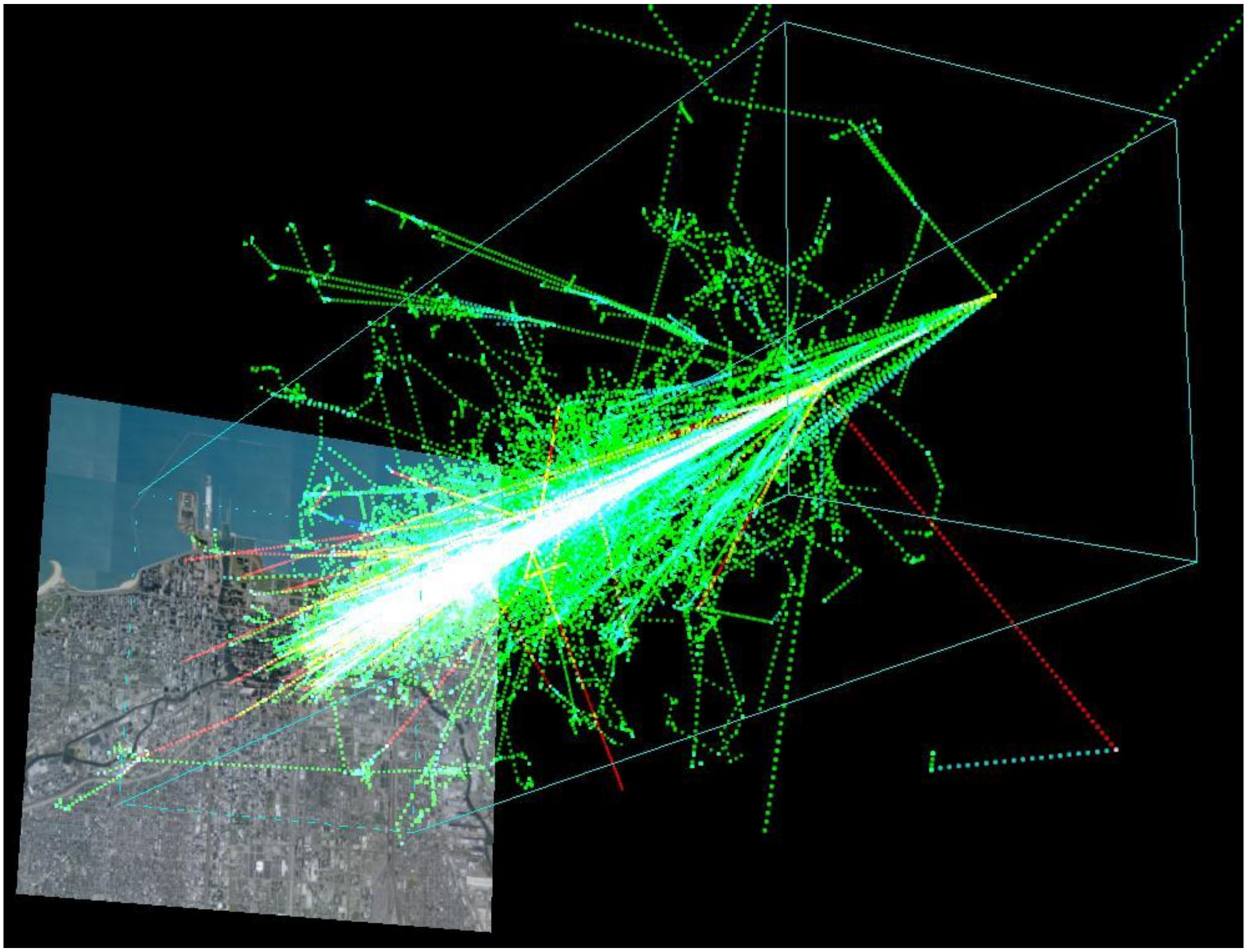


Figure 2c. This figure from a computer model shows an extremely energetic proton (coming in from the upper right) creating an air shower. The path of the original proton is labeled. (Image courtesy Maximo Ave, Dinoj Surendran, Tokonatsu Yamamoto, Randy Landsberf, Mark SubbaRao, and Sergio Sciutto and his ARIES package.)

2D. Misconception

Some people think that space is completely empty, except for stars and planets. If you could use your cloud chamber in space, however, you would find that the space contains many particles (not to mention electromagnetic fields). It is important to remember, though, that the "vacuum" of space is still more vacuous than anything achievable in a laboratory. The density is only a few particles per cubic centimeter!

2E. Assessment

Time: 10-15 minutes
Materials: Pencil, paper, and brains
Objective: The student will use what they have learned to create concise descriptions of cosmic rays.

Create a bumper sticker about cosmic rays. Then write one paragraph describing the science behind your bumper sticker.

Lesson 3: How cosmic rays affect humans

Objectives: Students will be able to describe why cosmic rays are dangerous to astronauts.

3A. Background material for the teacher

[Ask Question 1 here.]

On their trips to and from the moon, Apollo astronauts saw small white flashes of light while in the dark—even with their eyes closed (remember the Motivation for Students at the beginning of this booklet). They usually saw no more than a couple each minute, although at least one astronaut saw so many he had trouble sleeping. What caused these flashes?

The answer is cosmic rays.

Because of their high speeds, thousands of these cosmic rays were passing through the bodies of the Apollo astronauts every second. Most went straight through because atoms are mostly space (see Lesson 1). Some cosmic rays, however, hit atoms in the astronauts' bodies. The ones hitting atoms in the astronauts' eyeballs released a small amount of energy in the form of small flashes.

[Do Activity 1 here.]

To test whether cosmic rays were causing the flashes, scientists created the detector shown in Figures 3a, 3b, and 3c. It is the Apollo Light Flash Moving Emulsion Detector, or ALFMED. The emulsion was a gel-like chemical sensitive to cosmic rays. The astronauts would wear ALFMED over their heads for an hour and then time when they saw light flashes. The detector would keep track of when cosmic rays passed through itself and the astronauts' heads. It could also tell whether a cosmic ray had gone through the eye. On the ground, scientists found that when an astronaut saw a flash, a cosmic ray had passed through his eyeball!

More recently, the Italian Space Agency created a similar cosmic ray detector for the International Space Station (ISS); it is the Anomalous Long Term Effects in Astronauts' Central Nervous System, or ALTEA. It was on the ISS for much of 2006 and 2007. Figure 3d shows an astronaut performing an experiment with it. Although it looks similar to ALFMED, it is more complex. The helmet portion contains cosmic ray detectors that can tell whether a cosmic ray has passed through the brain. A device called an electroencephalograph (EEG) simultaneously measures the astronaut's brain activity. The results from this experiment will help determine how cosmic rays can affect the brain. The data are still being analyzed (for more information, see www.nasa.gov/mission_pages/station/research/experiments/ALTEA.html).

Cosmic ray collisions in the body can be harmful, because they can damage the DNA in cells. Remember, a single cosmic ray has a large amount of energy. If it collides with DNA, it will destroy part of that DNA strand. DNA contains instructions for the cell to function properly. When the DNA is damaged, then the cell will malfunction. Usually the cell will then die, but sometimes it can reproduce itself. If that happens on a large enough scale, the person may develop cancer.

Cosmic rays tend not to be a problem for a short mission. For example, the Apollo missions lasted no more than about a week. (A 2001 study, however, does indicate that even such a short mission increased the astronauts' likelihood of developing cataracts. See references in the Resources section.) Long term missions (at least six months) to the moon, Mars, or deep space, however, will increase the radiation risk. Therefore we must understand how this particle radiation affects the body.

We also need to learn how to best shield astronauts from cosmic rays. Unfortunately, shields require much mass to be effective. The more mass a shield has, the more likely it is for a cosmic ray to deposit energy in the shielding and not in the astronauts. Increasing the mass of a spacecraft, however, makes it more difficult and expensive to launch into space and to land. Current and future engineers have an important task ahead: to keep astronauts as safe as possible on such missions.

[Do Activity 2 here.]

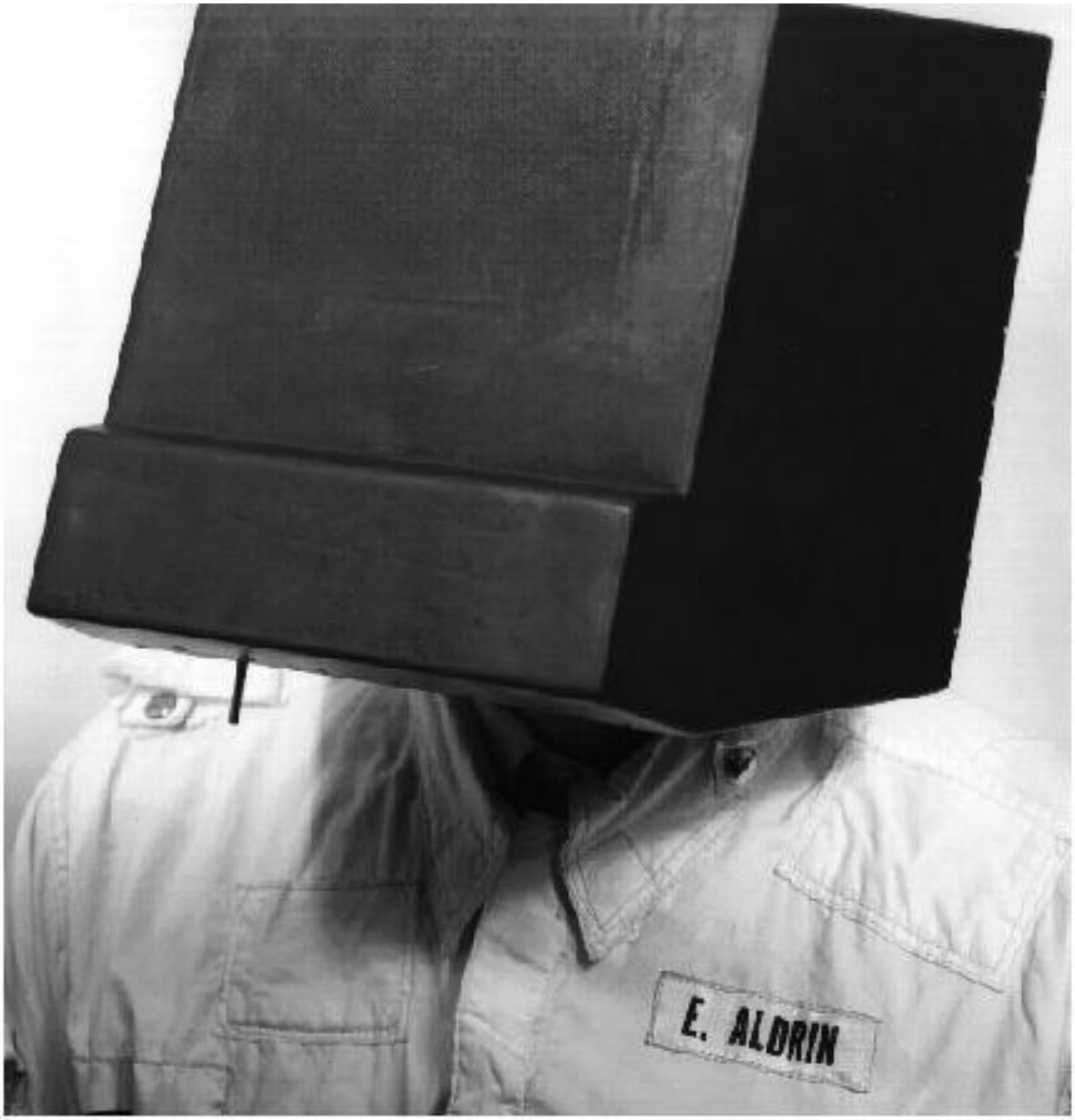


Figure 3a. Apollo 11 astronaut Buzz Aldrin (the second man on the moon), sports an attractive cosmic ray detector called ALFMED (Apollo Light Flash Moving Emulsion Detector). This picture was taken on Earth. Other astronauts wore it in space.

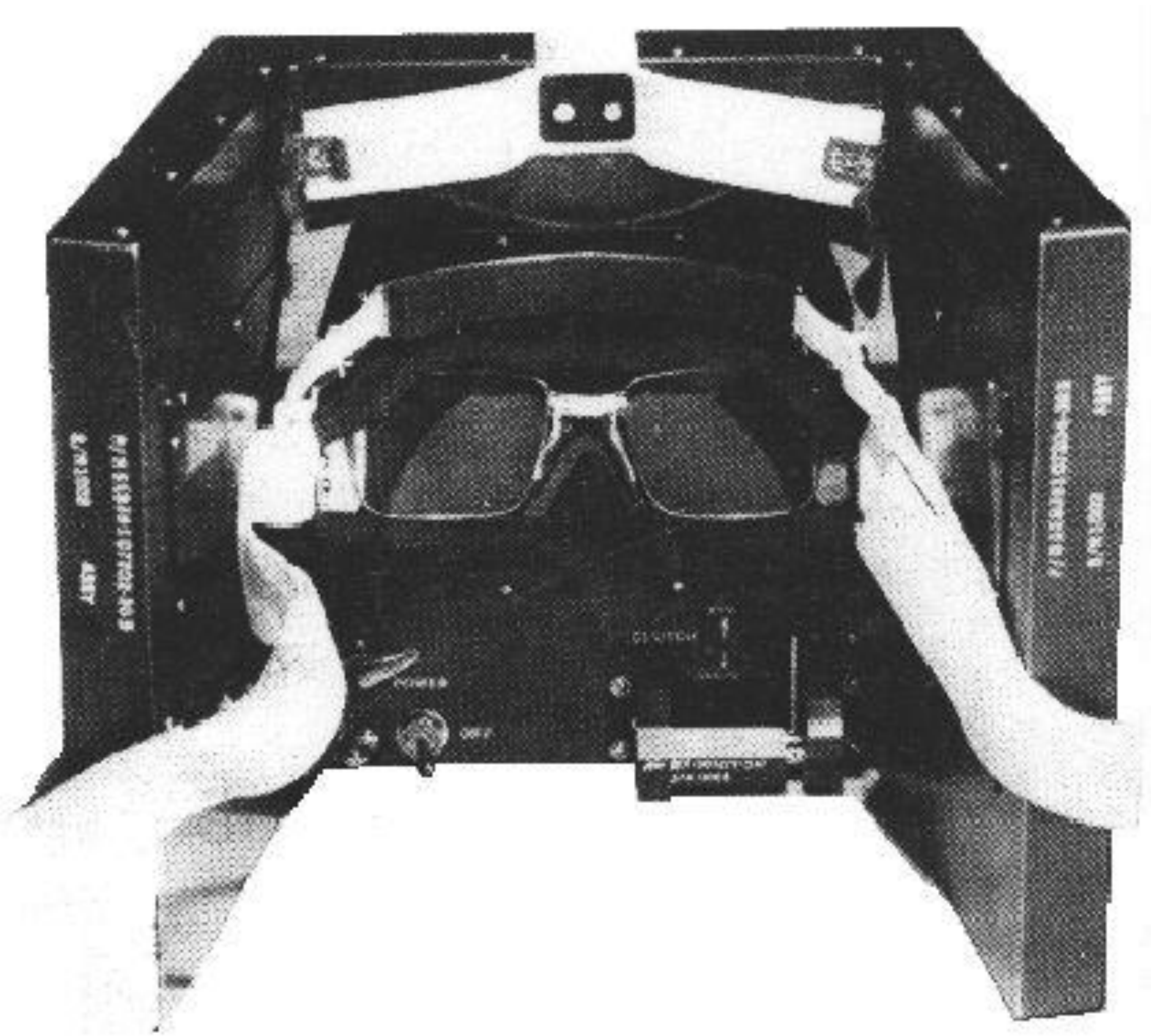


Figure 3b. This is the interior view of ALFMED. You can see the goggles to block out light (astronauts can only see the flashes in the dark) and the head strap.

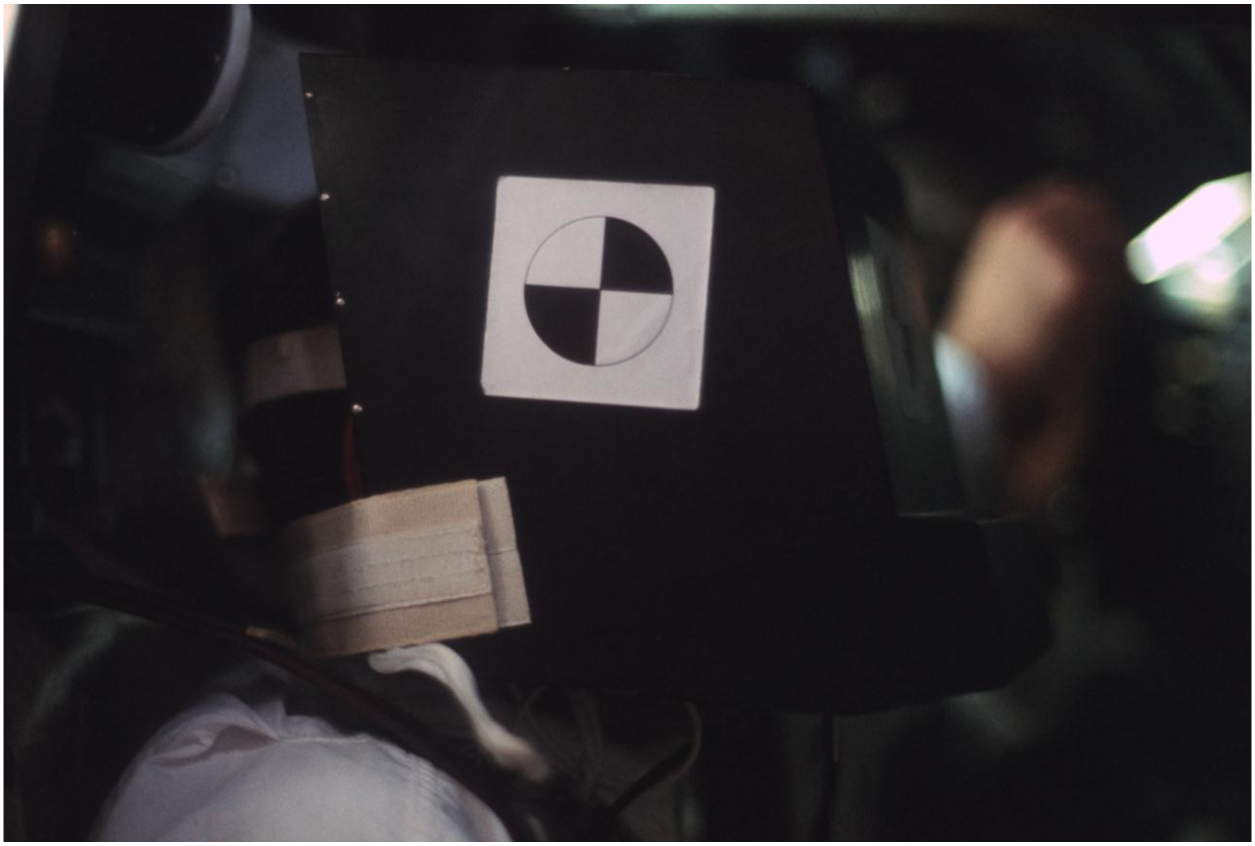


Figure 3c. Apollo 17 astronaut Ron Evans (facing right) wears ALFMED. You can see the back of his head and part of his ear on the left, just above the main head strap.

Figure 3d. Expedition 13 ISS (International Space Station) Science Officer Jeff Williams shows off Italian cosmic ray detecting headgear. He stayed in the ALTEA helmet for 90 minutes.

3B. Questions

Question 1

How might cosmic rays affect astronauts in space? (This is a discussion question that the ensuing lesson will answer.)

3C. Activities

Activity 1: Match Wits with Scientists!
Time: 15 minutes
Objectives: Students will learn to design a scientific instrument.
Materials: Pencil and paper

What experiment would you design to see whether cosmic rays hitting the eyeballs really do cause the flashes? Figure out what questions you need to answer. (Examples: are there cosmic rays in the spacecraft, do they go through the astronauts' eyeballs, do they go through their eyeballs when the astronauts see flashes? The experiment also requires timing of cosmic rays and timing of when the astronauts see flashes.) How does your design compare with what they actually did?

Activity 2
Time: At least 5 minutes
Objectives: Students will think critically about how to protect astronauts from cosmic rays.
Materials: Pencil and paper

Imagine that you are an astronaut setting up a base on the moon. What are some of the ways to protect you and your fellow crew members from the effects of cosmic radiation? What might make a good shield?

Possible ideas include creating an underground station or using a cave. Water is a good shield against cosmic rays, so students might decide to build a station near water ice. On the other hand, lead shielding is a dangerous idea (see the misconception in 3D). Trying a biological approach, such as repairing damaged DNA, is another possibility.

3D. Misconception

An important misconception is that lead can protect astronauts from cosmic rays. This is incorrect. Lead can actually be more dangerous than having no shielding at all! The reason is that when cosmic rays collide with the lead nuclei, they split the nuclei. These new nuclei are energetic enough to collide with and split even more nuclei. An astronaut on the other side of the lead shield will thus be bombarded by many more particles than just the original cosmic ray. Unless the shield is very thick, the radiation dose is higher with the lead shielding.

This is true of all materials, except hydrogen. Because hydrogen has only one proton in its nucleus, its nucleus cannot split into smaller parts. Therefore materials with a large amount of hydrogen in them, such as water and some plastics, make good shields.

3E. Assessment

Homework Assignment: Find a book at home or in the library that describes building a station in space, on the moon, on Mars, etc. Does it describe how to protect the astronauts from cosmic rays? If so, what is the method? Is it a good idea? Why or why not? If the book does not talk about cosmic rays, do you think that the astronauts would be in danger in that station? Why or why not?

Lesson 4: The Cosmic Ray Telescope for the Effects of Radiation (CRaTER)

Objectives: Students will be able to explain CRaTER's purpose and how it works.

4A. Background material for the teacher

The Lunar Reconnaissance Orbiter (LRO) is a spacecraft orbiting the moon (when you look at the moon, try to imagine that!). It launched 19 June 2009. It has three main goals:

1. Identify safe landing sites for future human missions to the moon.
2. Discover potential resources on the moon.
3. Characterize the radiation environment of the moon.

The third goal is vital to protecting astronauts on long missions, not just to the moon but also to Mars or deep space.

[Ask Question 1 here.]

LRO carries onboard seven scientific instruments. The primary one for analyzing the moon's radiation environment is the Cosmic Ray Telescope for the Effects of Radiation, or CRaTER (see Figure 4a). (See the misconception in section 4D). It studies both cosmic rays and how they might affect the human body. You can see in the picture that CRaTER sticks out from the spacecraft. This keeps the spacecraft from blocking cosmic rays from the instrument.

Figure 4b is a photograph of what CRaTER looked like before it was attached to LRO. The right-hand side of the instrument contains the particle detectors. A cut-away version is shown in Figure 4c. Inside are six detectors (D1, D2, D3, D4, D5, and D6). The detectors are made from silicon (see Figure 4d). When a cosmic ray hits a detector, it can create a small current in the silicon. A computer detects and records the amount of current created.

These detectors allow scientists to figure out how the number of cosmic rays arriving at the moon changes in time. That number varies, so tracking it for the duration of LRO's mission is important. This tells scientists how the radiation dose changes over time.

Scientists can also use the amount of current in the detectors to calculate how much energy the cosmic ray has and what type of ion it is (e.g. proton, helium nucleus, etc.). You might think that a more energetic particle would create a bigger current, but it's actually much more complicated. Calculating the energy and type of nuclei requires careful computer modeling and testing of the instrument detectors.

CRaTER does more than tell us the number, energy, and type of cosmic rays near the moon. It also helps scientists learn about how cosmic rays will affect humans on a long mission in space. Notice in Figure 4c that the six detectors are separated into three pairs. Two pieces of black plastic separate the three pairs of detectors. The plastic is a special type designed to mimic human tissue; it is called tissue-equivalent plastic or TEP (see Figure 4e). In other words, a cosmic ray will deposit the same amount of radiation in the TEP as it would in human tissue.

Let's see how this works. A cosmic ray will pass through the first pair of detectors. That tells us how much energy the particle had. If it has enough energy, it will also pass through the first piece of TEP. Along the way, however, it will lose some energy to the TEP. This means that the TEP is receiving a small dose of radiation. The cosmic ray will then pass through the next pair of detectors. Analyzing that signal tells us that the cosmic ray now has less energy. By comparing the cosmic ray's energy before and after it passed through the TEP, we can discover how much energy the cosmic ray lost. This energy is the radiation dose the TEP received.

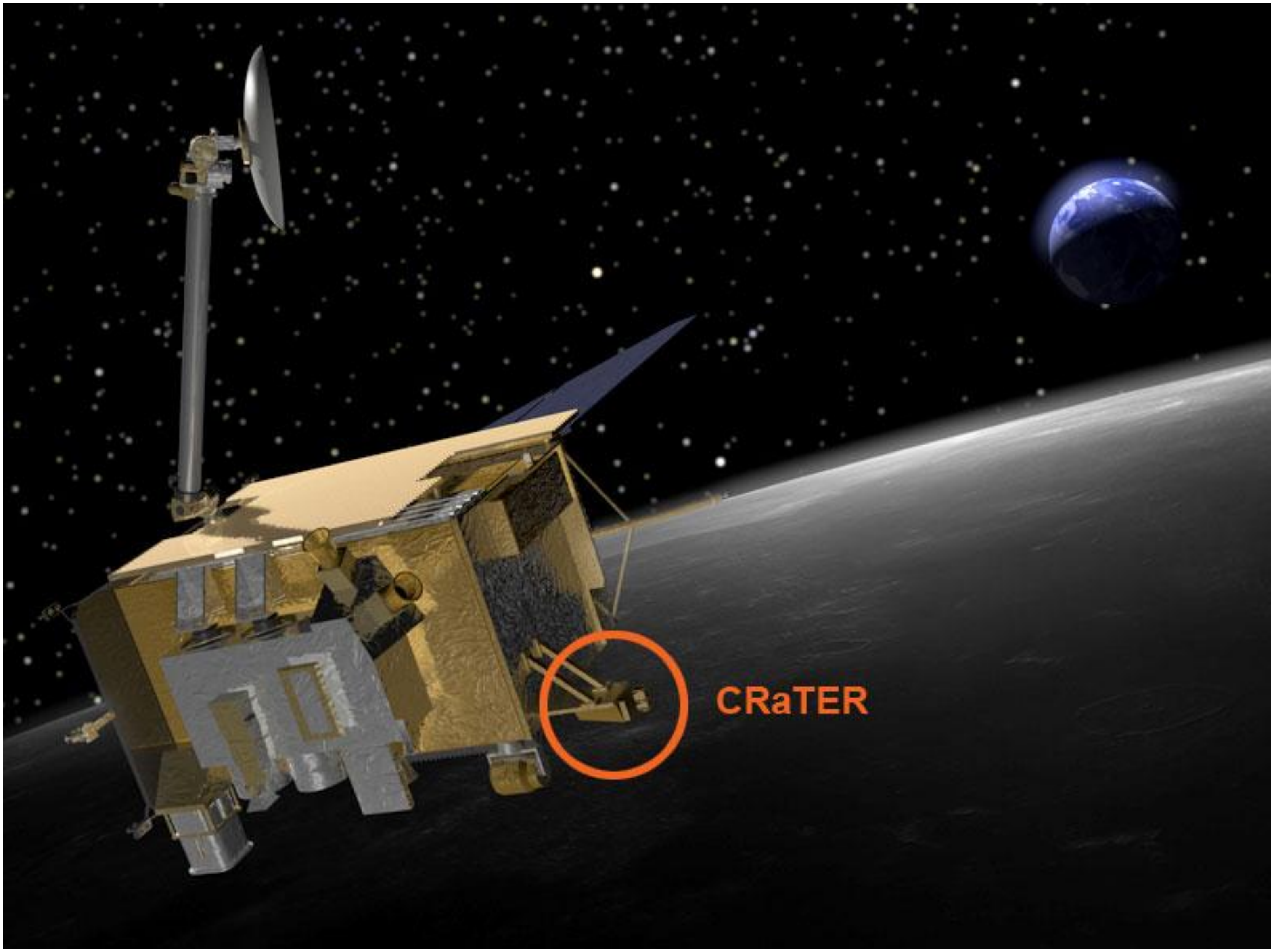


Figure 4a. An artist's concept of the Lunar Reconnaissance Orbiter (LRO) above the moon. The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) is circled.

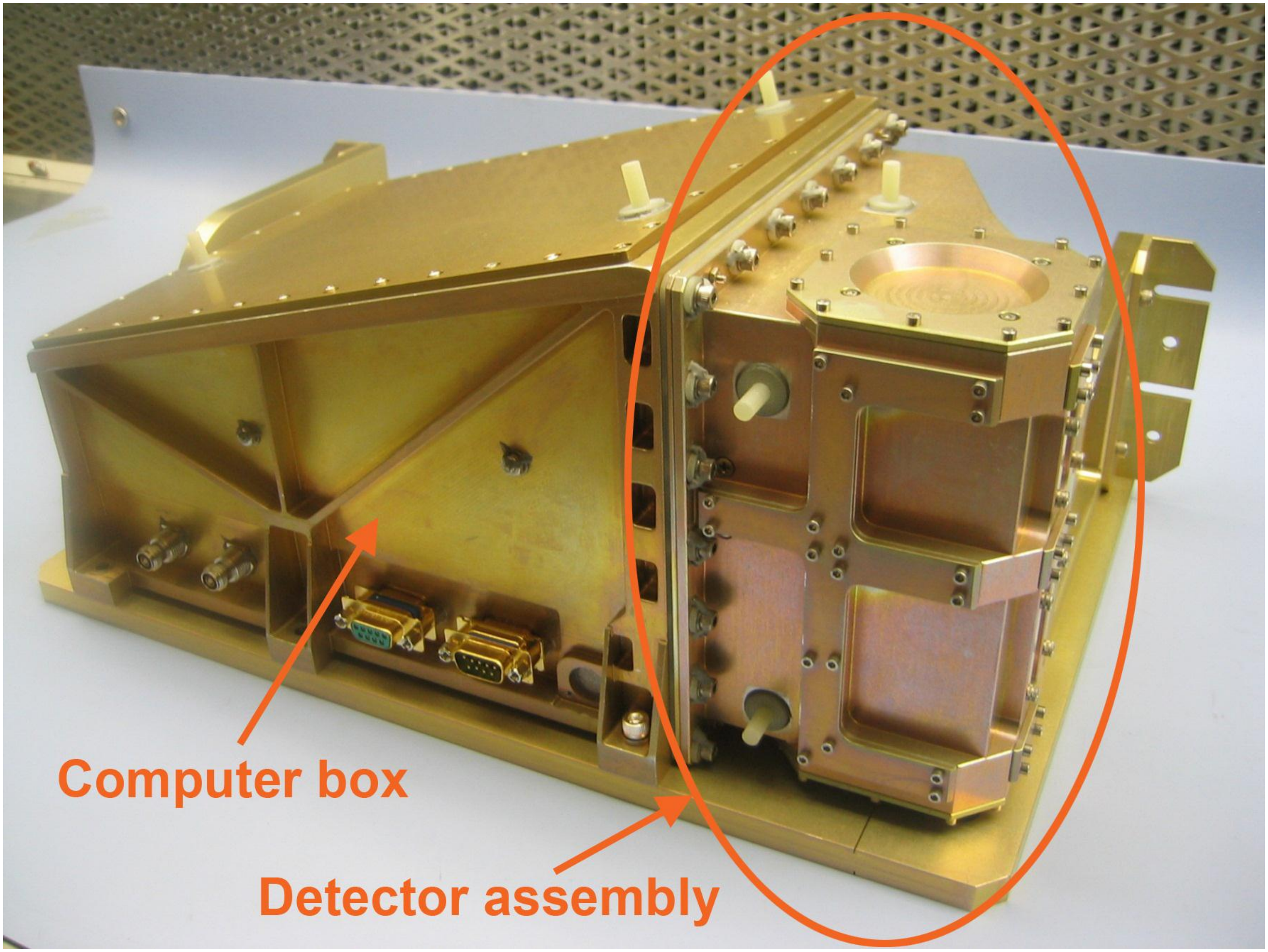


Figure 4b. CRaTER before it is attached to LRO. It has two parts: the detector assembly and the computer box.

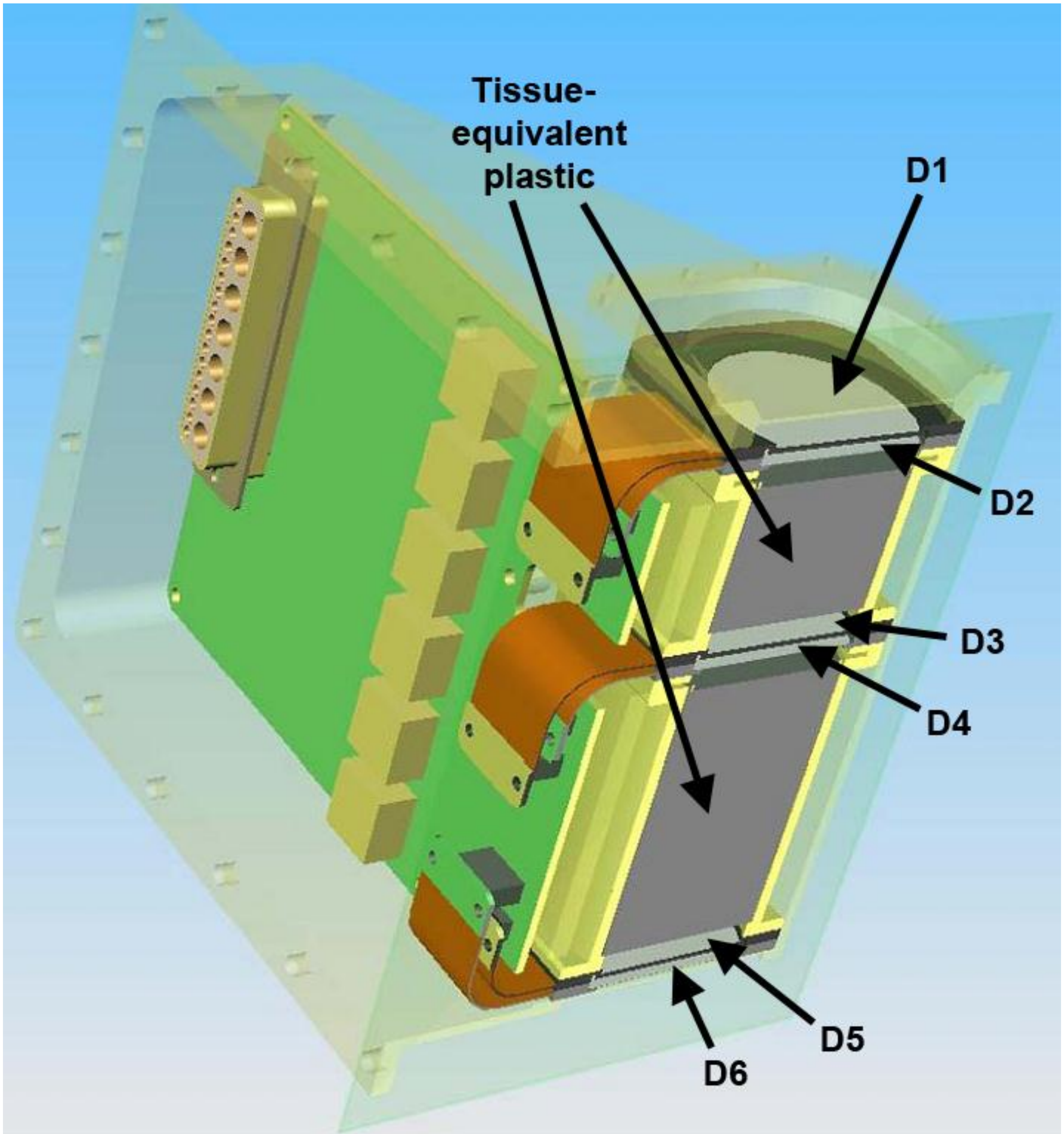


Figure 4c. This is a view of CRaTER's detector assembly. It (see Figure 4b) has six "eyes," or detectors (D1, D2, D3, D4, D5, and D6) and two pieces of tissue-equivalent plastic. D6 faces the moon, while D1 faces deep space. The "brain" of the assembly is the computer on the electronics board. This is plugged into the computer box shown in Figure 4b.

Figure 4d. This is an up-close view of a particle detector identical to the six in CRaTER (my finger is there for scale). The black plastic frame holds the disk. The disk is 140 micrometers thick and about 4 cm in diameter. The dark gray squares are the silicon, and the lighter edges of the squares are aluminum. The aluminum improves detecting the current created by cosmic rays. The wires run from the detector to a small computer. The detector is very reflective; in it you can see a fuzzy image of pictures hanging on my office wall.

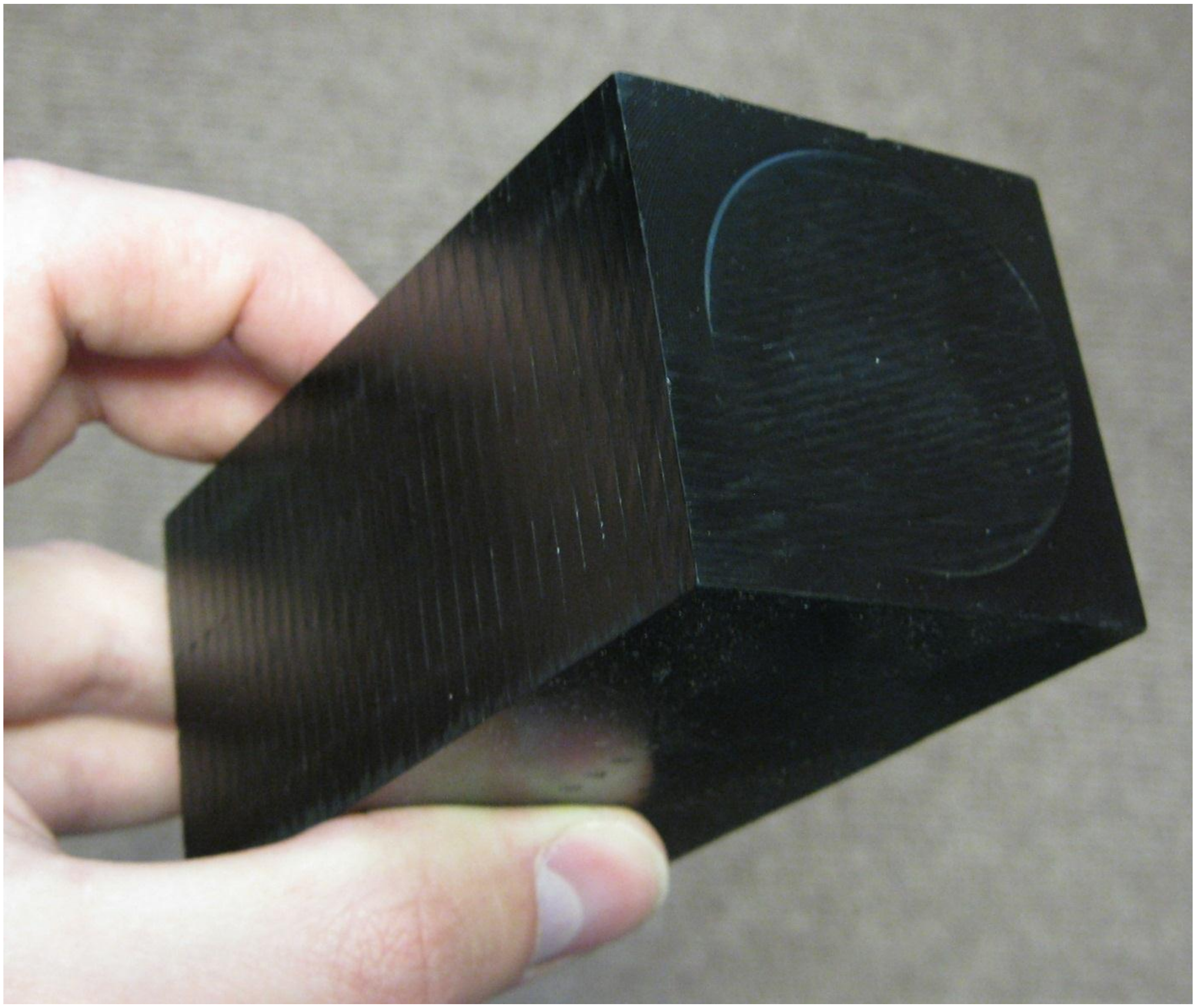


Figure 4e. This is tissue-equivalent plastic: hard and black. Even though it does not look like much, radiation interacts with it almost the same way as with human tissue.

4B. Questions

Question 1

Which of LRO's three goals do you find the most interesting? Why?

4C. Activity

Time: At least 30 minutes
Objective: Students will "design" a cosmic ray detector to answer their own questions.
Material: Pencil and paper

You are a cosmic ray scientist, and you need to design a cosmic ray detector for a spacecraft going to Mars. What questions would you like to answer? How will your instrument answer those questions? What do you need to consider when placing it on the spacecraft? Create a diagram of your instrument, and draw what it would look like on the spacecraft.

Answers will vary, but most detectors have some basic needs. They need an internal computer; this computer must connect to the main spacecraft computer, which in turn communicates with scientists on the ground. The instrument's computer needs to keep accurate records of time and the data it collects. Detectors also need electrical power, which comes via wires from the spacecraft itself. A human analogy may be useful for students: an instrument needs at least one sense (a detector) to interact with its environment, a brain (computer) to interpret the information from that sense, and food (electricity) to keep it working.

4D. Misconception

Even though CRaTER is called a telescope, it is not. A real telescope collects electromagnetic radiation to make distant objects appear closer. One example would be the type of telescope that you may have used to look at the moon; it collects and magnifies visible light. CRaTER, by contrast, detects particle and not electromagnetic radiation. It does not make distant objects appear closer. Calling it a particle detector rather than a telescope would be more accurate. But scientists enjoy making clever acronyms, so "telescope" it is! (Creating acronyms that have nothing to do with an instrument's purpose—CRaTER does not study lunar craters—is another matter entirely!)

4E. Assessment

Discussion Question: Write down three scientific questions that you have about cosmic rays that you think data from CRaTER could answer.

5. Final Assessment

Make a poster that explains possible origins of cosmic rays, how they affect people, and what protects us here on Earth. Or make a poster describing CRaTER's goal and how it works. Use resources at end of this packet or other ones your teacher approves.

6. Glossary and Acronyms

ALFMED: Apollo Light Flash Moving Emulsion Detector, designed to detect whether cosmic rays create small flashes in astronauts' vision
ALTEA: Anomalous Long Term Effects in Astronauts' Central Nervous System; a device onboard the ISS to determine how cosmic rays affect the human brain
Atom: the smallest particle that still has the chemical qualities of an element; composed of a nucleus and electrons
Cosmic ray: an ion or electron in space that travels at a speed similar to that of light
CRaTER: Cosmic Ray Telescope for the Effects of Radiation; an instrument on the Lunar Reconnaissance Orbiter designed to study particle radiation near the moon
Electroencephalograph: an instrument that records the brain's electrical activity
Electromagnetic radiation: energy emitted in the form of electric and magnetic waves
Electron: a negatively charge subatomic particle; one of three particles to comprise atoms
Electroscope: a scientific tool used to store electric charge
Emulsion: a gel-like substance used to detect electromagnetic or particle radiation
ISS: International Space Station
LRO: Lunar Reconnaissance Orbiter; a spacecraft designed to study the moon's resources and radiation environment
NASA: National Aeronautics and Space Administration
Nucleus: the core of an atom, consisting of at least a proton (in hydrogen), or protons and neutrons
Particle radiation: energy emitted in the form of subatomic particles
Phosphor: a material that, when stimulated, emits electromagnetic radiation
Proton: a positively charged subatomic particle; one of two particles to comprise atomic nuclei
TEP: tissue-equivalent plastic, which has radiation-absorbing properties similar to human tissue
Radioactivity: the condition of a substance to emit ionizing particle or electromagnetic radiation

7. Resources

Information about CRaTER and LRO
CRaTER's site: crater.unh.edu

A video in which the man responsible for CRaTER describes cosmic rays and the instrument:
www.nasa.gov/multimedia/nasatv/on_demand_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC_20090416_LRO_CRaTERvideo.asx&_id=190109&_title=LRO%3A%20New%20Window%20on%20the%20Universe&_tnimage=330170main_cratervid_100.jpg
(or you can search NASA's website, www.nasa.gov, for the video entitled "LRO: A New Window on the Universe")

LRO site: lunar.gsfc.nasa.gov

General information about cosmic rays
Unfortunately, I have been unable to find a good introductory book on cosmic rays. The best is:
Michael Friedlander, *A Thin Cosmic Rain: Particles from Outer Space* (previously published as *Cosmic Rays*), Cambridge, MA: Harvard, 2000.

Cosmicopia: An Abundance of Cosmic Rays (a NASA Goddard website about cosmic rays):
helios.gsfc.nasa.gov/cosmic.html

Cosmic ray comic book (this is excellent!): www.scostep.ucar.edu/comics/books/, then click on the file labeled cosmicrays_e.pdf.

Air shower movies generated from the ARIES (Air shower Extended Simulations):
astro.uchicago.edu/cosmus/projects/aires

DSLR article

Space Radiation
Space Radiation Analysis Group at Johnson Space Center: srag-nt.jsc.nasa.gov

Eugene N. Parker, "Shielding Space Travelers," *Scientific American*, March 2006.

M.G. Lord, "Are We Trapped On Earth?" *Discover*, June 2006.

Cosmic rays and cataracts: science.nasa.gov/science-news/science-at-nasa/2004/22oct_cataracts

A NASA 6-12 educators guide to radiation math, with worksheets for students:
www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation_Math.html